PB-215 462

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10 March 1959

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PB 215 462

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1959

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Cincinnati, Ohio

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Springfield VA 22151

Presented at the Conference on Solids Separation from Gaseous and Liquid Industrial Wastes, sponsored by Mid-Atlantic States Section Air Pollution Control Association and New Jersey Sewage and Industrial Wastes Association Industrial Wastes Committee, Atlantic City, New Jersey, March 10, 1959.

EFFECTS OF AEROSOLS IN THE COMMUNITY ATMOSPHERE

I. Introduction

This discussion will be mainly concerned with the effects of aerosols in the community atmosphere as distinguished from the occupational environment. Research in the latter area, however, at present constitutes our only knowledge for many biological effects. Material has been gathered from a literature review of some 60 sources and is presented in summary style. The subjects considered are the biological, physical and economic effects of atmospheric pollutant aerosols.

The term aerosols, as used in this discussion, refers only to the particulate phase, either solid or liquid, of gaseous dispersions of fine particles. This definition immediately precludes consideration of the direct effects of the gaseous contaminants which often exist concurrently in particulate-gas systems. Consideration is given to the possible carrier and/or catalytic nature of particulates which sometimes may account for the detrimental effects attributed to the aerosol, in both biological and physical systems.

Aerosol particulate matter may exist in any one of several forms. Dusts consist of solid particles dispersed in a gaseous medium as the result of the mechanical disintegration of matter. Smokes are gaseous dispersions of fine particles of low vapor pressure formed by combustion, chemical reaction or condensation. Fumes are a class of smoke particles resulting from the combustion of metals and are usually formed simultaneously with a gas. Mists consist of droplets formed by the condensation of water vapor upon suitable nuclei or by the atomization of liquids. A fog is a mist of sufficient concentration to reduce visibility. Smog usually refers to a combination of fog and smoke pollution. The Los Angeles variety, however, is not associated with fog but is rather a complex mixture of gases and fine particles formed in part by chemical reactions in the atmosphere. Aerosols formed in this way are best classified as smokes, according to the definitions above.

Dusts are always solid; smokes may be solid or liquid; and mists are always liquid, sometimes containing dissolved or suspended solids. Air Pollution literature usually refers to "smoke" as that aerosol which is formed by incomplete combustion. This aerosol is a mixture of carbon, tar droplets, fine ash particles and, at times, acid droplets. It therefore contains smoke, dust, and mist particles. "Atmospheric dust" is the total particulate load in the atmosphere, including dusts, smokes and mists, from all sources.

II. Biological Effects of Aerosols

A. On Man

1. Effects on Respiratory System

These effects are due primarily to interactions of the aerosol with the tissue of the lung passages. In community atmospheres the effects may be similar to the reactions caused in industrial environments, except that in the latter case exposures are for shorter periods to higher concentrations. In the former case accurate assessment of physiologic damage is very difficult since changes, if they occur, are very slow. Exceptions to this occur during short term exposures to comparatively high concentrations in the atmosphere which may occur during stagnant stable weather patterns.

For the case of industrial atmospheres, Drinker and Hatch have reported that aerosols can produce lung damage.(1) They show that the pneumoconiosis-producing dusts such as silica, asbestos, silicates, carbon and beryllium act by producing irreversible fibrotic changes and the development of aerosol-bearing nodules in the lung. These changes result in reduced lung capacity characterized by shortness of breath and lessened capacity for work. Certain inert dusts may also produce pulmonary change, depending on the condition of the respiratory tract, as reported by Vorwald.(2)

As distinguished from the pneumoconiosis producers certain aerosols can produce toxic effects.(1) Lead aerosols may be absorbed through the lungs into the blood stream and exert systemic effects. Radioactive aerosols can produce radiation damage locally at their deposition point in the lung or, if passed into the blood stream, may center in the bone marrow and cause indirect damage by destruction of the blood forming tissue. Chromates and arsenical aerosols attack the respiratory passage walls and have been shown to produce perforation of the nasal septa and, in some cases, cancer of the respiratory tract. Other aerosols such as those containing cadmium, selenium, tellurium, vanadium, and fluorides produce effects ranging from upper respiratory irritation to lung edema. A transient disturbance often results from breathing heavy concentrations of metal oxides such as the oxides of zinc, copper, lead and manganese, i.e. "metal-fume fever". This is caused by absorption of protein material formed by the action of fume particles on respiratory passage tissues.

These problems of industrial atmospheres have been cited to show some of the possible effects from exposure to comparatively high concentrations of aerosols. The effects of low concentrations of aerosols in the general community atmosphere have been studied only by inference either statistically from mortality and morbidity data or by laboratory exposure of animals to low concentrations of aerosols found in the atmosphere.

Aerosols produced in the combustion of fuels have received considerable, although still inadequate, attention.(6,10,15,16,17,19) These consist of carbon, tar, mineral ash, and acid mists, in proportions depending on the methods of combustion and fuel composition. The organic portion has been shown, in preliminary work, to contain up to 0.10% of the highly carcinogenic substance 3,4-benzpyrene.(61) Falk and Kotin have shown(3) that this and similar polycyclic hydrocarbons are carried by carbon particles into the lungs, where their

release from an adsorbed state may be accomplished by the action of irritant gases, freeing them for carcinogenic action.

British workers investigating the relationship between lung cancer death rates and exposure to benzpyrene from both tobacco smoking and general air pollution demonstrated that about one-half of these deaths may be associated with cigarette smoking, and about three-fourths of the remainder with a factor only slightly present in rural areas, presumably air pollution.(12) Russian estimates are more definite: "Fifty cigarettes would have to be smoked in order to expose the smoker to as much 3,4 benzpyrene as is inhaled daily in some industrial towns".(13) This carcinogenic substance occurs in the particulate phase of gasoline engine exhausts(14) and in the combustion products of solid, liquid, and gaseous fuels.(15)

Liquid as well as solid aerosols are of importance in producing respiratory damage. Sulfuric acid mist, which can be formed by oxidation of SO_2 in the atmosphere followed by condensation of water on these SO_3 nuclei, has been shown by Amdur, et al. to be highly toxic.(16,17) Other acids formed in industrial processes, may be emitted in droplet form, e.g., HF, HCl, CH_3COOH. These can then exert irritant effects in the lung, the site of action depending on their solubility.(18)

The role of particulates as a synergistic agent in intensifying gaseous pollutant effects has also been indicated.(4) In the London fog episode of 1952, which was followed by an unexplained increase of some 4,000 deaths during a two-week period, the suspended smoke particle concentration was 16 times the average. According to Regan,(5) this smoke concentration acting jointly with a SO_2 concentration of 10 times the average was contributory in the increased death rates from bronchitis and pneumonia. It is not probable that the SO_2 exposure could have, by itself, produced these dire consequences. The exact mechanisms of the combined action of the particle-gas

exposures is unknown and recent work[6,7] is contradictory. Synergism, antagonism or no modification may be produced by a number of physical, chemical, and biological factors. Perhaps the explanation suggested by LaBelle, et al.[8] may account for the synergistic action: soluble gases which are normally removed by absorption in the upper respiratory tract may be carried by aerosol particles into the alveoli to exert their damaging effects in a more critical region. Thus, vapors which normally have a low lung penetration become more toxic in the presence of aerosol particles with which the vapor becomes associated by absorption, adsorption or solution.

The possible long term effects of exposure to low level concentrations of aerosols in the atmosphere are recognized.[9] Published results are difficult to interpret in any attempt to assess the portion of the problems which is due to aerosols alone as distinguished from total air pollution. For example, respiratory disease among English postmen has been shown by Fairbairn[10] to correlate with the incidence of fog, and presumably air pollution levels. The levels of Los Angeles-type smog were shown by Mills to have a significant relation to the day-by-day respiratory and cardiac deaths of the exposed population;[11] although recently temperature, rather than smog, has been shown to be the significant factor. Statistical studies by the Mellon Institute over 40 years ago[19] showed a good correlation between the smokiness of a city and pneumonia mortality. Twenty-five years ago a survey of 14 cities by the Public Health Service showed pneumonia deaths correlated with air contamination.[20] The medical research program of the Public Health Service is now investigating long term chronic effects by statistical and field studies which are attempting to relate air pollution measurements with morbidity and mortality data.[21]

2. Mucous Membrane Irritation

In addition to action through the respiratory system, aerosols can also exert effects directly on the exposed mucous membranes of

the body. Eye, nose, and throat irritation is the main complaint arising from exposure to Los Angeles-type smog. Recent work by Merrifield and Graham[22] has established that the irritation is partially due to the aerosol phase of the smog complex. A possibility here is the synergistic action of these particulates holding irritating gases in loose combination.[9] Dautrebande, et al. have shown that liquid aerosols produced from formaldehyde, nitric acid and sulfuric acid can be responsible for eye irritation.[23] In London-type smog, indications are that the irritant substances may be acidic salts, particularly metal ammonium sulfates.[24]

3. Loss of Beneficial Solar Radiation

An indirect effect of the aerosol phase of polluted air is the obscuration of sunlight and consequent loss of beneficial radiation. Recent studies by Hand[25] have shown that, in winter, total radiation intensity in a large city averaged one-fifth less than that at a suburban point ten miles away, at times being only ten percent of that received by the suburtan station. The loss of beneficial ultraviolet radiation is much greater than the loss of total radiation; a loss of a few percent in total solar radiation almost completely robs the radiation of its ultraviolet component under the usual urban conditions. Although loss of this vital component, the only natural source of Vitamin D, is undoubtedly important, no work has yet been done to assess this loss in terms of health effects because of the concurrent effects of the air pollution per se. The psychological effects of life in a darkened environment are, of course, adverse to emotional health.

4. Odors

Whether aerosols in themselves can create odor nuisances is a moot point. McCord[26] states categorically that odors are produced only by gases and vapors. This should not exclude the possibility of odors arising from particulates with significant

vapor pressure. Significant, in this case, can be an extremely low value since odors are often produced by vapor concentrations in the order of fractional parts per billion (e.g., mercaptans, skatole, vanillin). There is also the strong possibility that aerosols can "carry" odorous gases in loose combination, possibly by adsorption.

B. On Agriculture

1. Vegetation

Pollutant aerosols in the community atmosphere exert effects on vegetation in several ways. Settleable solids may reduce the amount of light reaching the leaf by deposition on the leaf surface, thereby affecting plant growth. These solids may also clog the stomata, reducing carbon dioxide transfer and interfering with photosynthesis. Vegetation may be indirectly affected by the reduced amount of sunshine to which it is exposed because of a smoke pall.

Specific injury can occur with certain pollutant aerosols. Sulfuric acid mist becomes toxic to plants on settling on their leaves.(27) Particles greater than 1μ in diameter produce a definite "bloom". When the leaves are wetted characteristic acid spotting is produced. Water soluble particulate fluorides can affect plant structure directly, although most of the damage from fluorides is attributed to the gaseous phase.(28) Herbicides may also affect vegetation through poor air-borne spraying practices (i.e. when winds carry herbicides to neighboring susceptible crops) under which conditions the aerosol becomes a true air pollutant.(29)

It is possible that some of the weathering and spotting of vegetation attributed to Los Angeles-type smog is due to the particulate phase of the smog and not to gas injury.(27) In heavy smog, droplets deposited on leaves wet the surface. These particles

are acid (pH=3.0) and produce weathering and a "shot-hole" type injury.

Air-borne industrial wastes may contain the same ingredients as commercial weed killing dusts. The following materials have been shown to kill or injure vegetation when exposures were in the order of several pounds per acre: ammonium sulfate, ammonium thiocyanate, borax, calcium cyanamide, copper nitrate, copper sulfate, cryolite, iron sulfate, sodium arsenite, sodium chlorate, sodium chloride, and sodium nitrate.(30)

The absorption of radioactive elements by plant life due to settling radioactive aerosols (radioactive fallout) has been receiving considerable attention. It has been recognized that part of the Strontium 90 descending to the earth's surface in fallout from nuclear test explosions will lodge on foliage and part will enter the soil.(31) Information is lacking as to the extent of direct damage, if any, to plants from this source. The greatest hazard here appears to be the possible transfer to man and animals of concentrated sources of radioactive material.(32)

2. Livestock

Farm animals are affected by pollutant aerosols in a two-step process. Air-borne contamination may be accumulated in vegetation and forage and concentrated there possibly without causing any visible damage to the plant-life itself. The animals are affected by ingestion of this contaminated vegetation.

Aerosols of arsenic, lead, and copper fumes produced as wastes in smelter operations have been shown to contaminate vegetation and thence affect livestock.(33) Acute arsenic poisoning can kill in a few hours while chronic poisoning may eventually result in paralysis and death.(34) Acute lead poisoning can be fatal while chronic poisoning is often characterized by paralysis of the animal's larynx, often followed by pneumonia.(35)

Fluoride aerosols such as the sodium aluminum fluorides, apatite, calcium, fluoride, etc. are often emitted from industrial processes. This particulate matter accumulates on the exposed surfaces of vegetation and can affect animals by ingestion. The fluorides act as a cumulative poison to animals, the effects varying from teeth damage to death.(36)

It is also known that ingestion of vegetation contaminated by settled radioactive aerosols has at least an indirect effect on animals. The milk of dairy cattle which graze in contaminated areas show increases in Strontium 90 content.(37)

III. Physical Effects

A. Reduction in Visibility

One of the most important effects of aerosols in the atmosphere is the decreased visual range through the aerosol cloud. The degree of lessened visibility depends on the physical properties of the material, its size distribution, and its concentration. Approximations of visual range dependence on weight loadings of atmospheric aerosols have been made.(38) For water droplets, particle size dependence shows that at a concentration of 1.0 mg/m^3 the visual range will decrease from about 4.5 miles to only 0.3 miles if the average droplet diameter is reduced from 7.3 to 0.73 microns. With a further decrease in size visibility again increases. In terms of concentration only 0.3 mg/m^3 of 0.73μ droplets are necessary to produce the same visual range (1 mile) as 4.5 mg/m^3 of 7.3μ droplets. Smoke investigations in England(39) have shown that visual range is inversely proportional to aerosol concentration, i.e. when smoke concentration doubled visual range decreased about one-half.

Pollutant aerosols affect visibility in two ways. Besides their direct effect of light absorption and refraction, they may also be important as condensation nuclei for fog formation. It has been found

that both cloud and fog nuclei orginate, at least in part, from combustion product aerosols which are mixtures of hygroscopic and non-hygroscopic substances.[40] This problem has received attention in relation to the reduction of visibility at airports caused by aerosols from jet exhaust acting as fog nuclei.[41,42] Not only does the presence of combustion aerosols contribute to fog formation but they also have been shown to increase fog persistence.[43] The high electrostatic charges that combustion aerosols possess tend to prevent coalescence of fog droplets formed on these nuclei.

The use of visibility criteria as a qualitative measure of air pollution has been attempted but is fraught with many difficulties. In spite of these difficulties observations of visual range have been recorded because of a practical interest. In Czechoslovakia "observations from 1800 on, all taken at the same position and by the same rules, show an average of 82 days of fog per year for the period 1800 to 1880. Since 1880 the average number of foggy days per year has nearly doubled and it is since that time that the city has become markedly industrialized".[38] Data are available which also show evidence on the basis of visibility measurements that atmospheric pollution has increased in France, England and the United States. In the Leicester study,[39] visibility correlations with smoke density records were attempted but showed low significance, indicating that aerosols other than black smoke contribute significantly. Johnstone[44] has suggested that sulfuric acid mist is one of the principal causes of low visibility. Smoke density measurements do not include a measure of this or other liquid aerosols. In Los Angeles, aerosols in the 0.5 to 0.8 micron range have been listed in order of their occurrence in the atmosphere and, presumably, of their importance in decreasing visual range: other soluble aerosols, sulfuric acid mist, carbon and inorganics.[38]

B. Effects on Exposed Surfaces

1. Corrosion of Metals

Corrosion is considered to consist of slow chemical and electrochemical reactions between a metal and its environment. The effects of deposited aerosol particles in the corrosion of metals have been summarized[45] and depend on (a) the quantity of water soluble components of the aerosol; (b) the pH of the resulting solutions and their SO_4 and Cl ion concentrations; (c) the adsorption isotherm of water vapor; and (d) the SO_2 adsorption capacity of the resulting solutions. Aerosols containing water soluble SO_4 and Cl ions may be expected to exert weak corrosive action. These ions hydrolyze to produce acids which initiate the corrosive action. In essence the deposited aerosol particles act as nuclei which, in humid atmospheres, or when wetted, produce electrolytic corrosion. Hygroscopic salts can initiate corrosion even at low relative humidities.

The effects of several solid contaminants on coated and uncoated steel have been determined.[46] Particles of carbon and tars which settle on surfaces are especially important since they can promote corrosion either by adsorption of acid gases and water vapor (by carbon) or by the action of the tarry acids directly.[47] In addition, these tars are sticky and cling tenaciously to exposed surfaces.

All metals do not behave similarly when exposed to particulate pollution. Metals such as iron which do not form protective corrosion products can corrode at a rate as high as 100 μ/year.[48] Other metals form corrosion-resistant films which hinder further attack. These metals include aluminum, lead, zinc, brass, copper, nickel, and magnesium.[47] Certain other metals such as stainless steel and chromium-plated products are almost completely corrosion resistant. The most important factors other than the properties of the deposited aerosol are the purity and surface condition of the metal, the temperature and relative humidity and the presence or absence of corrosive gases.[48]

2. Damage to Stone, Masonry, and Other Materials

Carbonate-bearing stone such as limestone is often affected by particulate pollution. Adhesive acid-bearing tar droplets can convert the carbonates to sulfates, which are soluble in rainwater, leaving pitted surfaces.(47) The degree of attack has been shown to be a function of the porosity of the stone, pitting appearing if the index of porosity exceeds 13 percent.(49) Other building materials become covered with incrustations which eventually break off leaving marred surfaces.

Textiles, leather, and rubber products are also vulnerable to pollution. For these materials, however, gaseous pollution appears to be the principal problem.(47)

3. Soiling

Soiling is the most obvious and complaint-arousing effect of atmospheric aerosols. Coarse particles settle on horizontal surfaces such as streets and sidewalks, automobiles, porches, window sills, etc. rapidly covering them with unattractive films. Physical damage occurs when these materials are removed because of their abrasive action.

The fine particles are of a more insidious nature. They are carried easily by air currents through cracks around window frames into homes where they attach themselves to walls, draperies, upholstery, carpets, and clothing. Closing windows and doors is of no great help since in the average well-constructed home the air is changed several times an hour through infiltration. Consequently, the housewife is continually fighting a loosing battle against fine particulate pollution. Although these particles do not settle readily they are deposited by thermal and electrostatic forces(50) on nearly every exposed surface in the home. This problem is not peculiar to homes but is also important in

certain industries (e.g. precision parts, paper, food, pharmaceutical, photographic films), in stores, office buildings, hospitals and hotels.

IV. Economic Effects

Atmospheric pollutant aerosols produce an economic burden on individuals, industry, and communities. Reduction in visibility affects transportation operations, both ground and air. Increased operational costs, passenger inconvenience, and additional safety hazards which can result in personal injury and property damage, result. The obstruction of natural light results in an increased cost of electricity for artifical lighting of streets and buildings.

Corrosion and soiling of metals and building materials requires extra costs in protective coatings or in cleaning or replacement of exposed surfaces. Soiling of merchandise, household articles and clothing results in direct or indirect losses. Frequent laundering and dry cleaning of exposed textiles are required which is costly in itself and results in a shorter usefulness of the article. Soiling of manufactured products can result in lowered product value or, in some cases, complete loss of product worth (e.g. precision machinery and photographic films). Expensive air filtration equipment becomes necessary not only to control effluents but also to prefilter supply air. (Equipment used primarily for air conditioning is not usually designed to remove fine particulate aerosols efficiently.)

Farmers and florists suffer considerable losses due to the air-borne particulate effects on vegetation and livestock. The scenic value and recreational facilities of communities are often impaired. Property devaluation in highly polluted areas represents an important economic loss. The health of the community is affected resulting in lessened human efficiency, absenteeism and in personal discomfort arising from the physiological and psychological effects of air-borne solids. In some acute cases, human life itself can be destroyed.

Several estimates of the costs of air pollution have been attempted. In most cases these estimates have been confined to detrimental effects measureable in terms of money. No account is taken of the direct and indirect effects on human health and well-being. Such estimates have been made considering air pollution as a whole. The portion of the cost attributale to aerosols alone is difficult to assess. Certainly it is a significant fraction, perhaps even half or more of the total cost.

It was estimated in 1952 that the total direct cost in the United States — including only the extra costs of cleaning, painting, laundry, and damage to merchandise and buildings — was $1.5 billion/year or about $10/capita/year.(51) The figure for England in 1954 was 10 pounds/capita/year. This figure included some indirect costs and was for highly polluted areas.(52) In 1949 an estimate of from $8 to $20/capita/year was made for the United States.(53) In 1941 the estimate was $2.5 billion annually.(54) The per capita cost in U.S. cities was estimated at $17.00 per year in 1949, with a total annual cost in some cities of as high as $50 million (Chicago).(53)

In an attempt to assess the health costs of urban air pollution it has been estimated(55) that roughly 700 deaths per year occur in Chicago alone as a result of the respiratory hazard of the polluted atmosphere. Of course in short-term acute attacks of high intensity pollution the death rate attributable to air pollution can rise to levels much greater than this. (See Biological Effects on Man).

It was pointed out in a recent article that although economic losses, exclusive of health effects, are as high as $10 to $20/capita/year, the cost of enforcement of air pollution ordinances designed to reduce this economic burden amounts to only 15¢/capita/year.(56) Industrial management has shown its willingness to assume its share in abating the pollution problem. It was estimated in 1955 that U.S. industry was spending between $100 and $300 million annually in air pollution control efforts.(57) The problem can not be considered due to industry alone. In a comprehensive

study of the sources of pollution in Louisville, Kentucky, it has been shown that pollutant aerosols from domestic sources account for a significant portion of the total aerosol burden in the western portion of the city (30 percent, by weight).[58] To attack this problem more attention should be given to practices of efficient and smokeless fuel combustion. That community action can reduce the pollutant load to the atmosphere has been amply demonstrated in cities such as St. Louis[59] and Pittsburgh.[60]

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